

Probing proton spin structure via heavy flavor production in PHENIX



STRANGENESS IN QUARK MATTER

24 - 29 June 2007

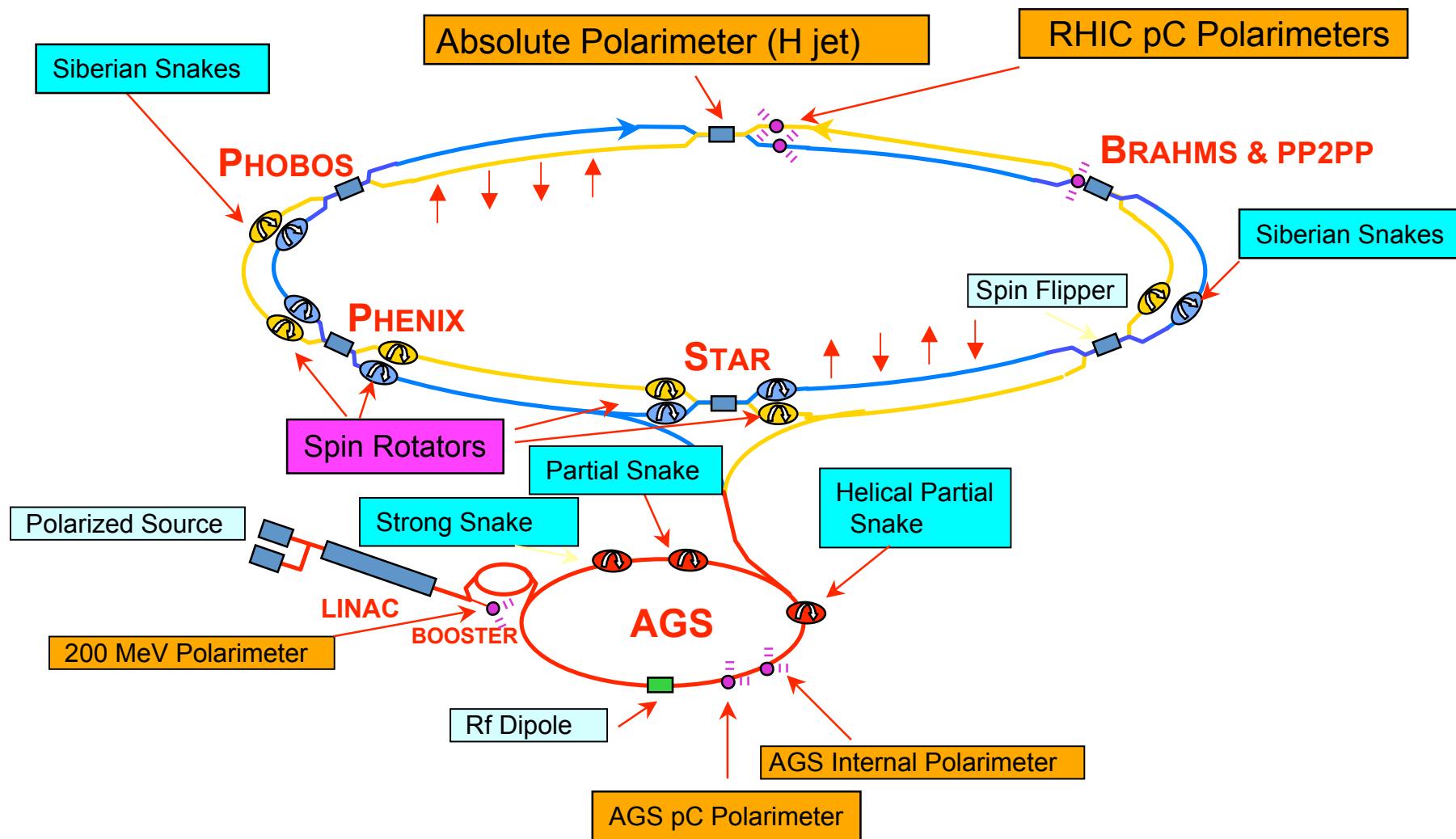
Levoča, Slovakia

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RHIC as a Polarized p+p Collider



Proton Spin Structure at PHENIX

First moment of the
Spin dependent
Gluon distribution
 ΔG

Transverse Spin

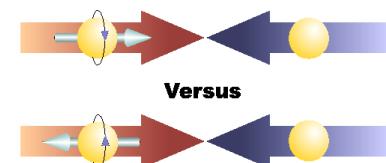
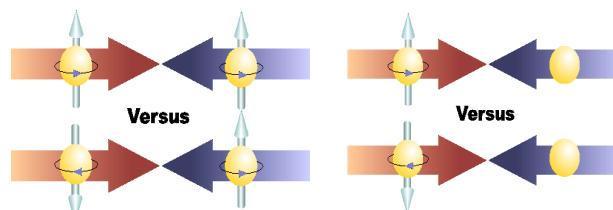
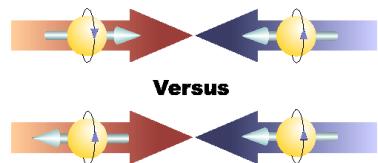
Flavor separation of
the quark and
anti - quark sea
 $\Delta \bar{q}$ and $\Delta \bar{\bar{q}}$

Inclusive Hadron Production
 $A_{LL}(gg, gq \rightarrow h + X)$
Prompt Photon
 $A_{LL}(gq \rightarrow \gamma + X)$
Heavy Flavors
 $A_{LL}(gg \rightarrow c\bar{c}, b\bar{b} + X)$

Single Spin Asymmetries A_N
Transversity δq_i
 π^+, π^- Interference fragmentation :
 $A_T(p_\perp p \rightarrow (\pi^+, \pi^-) + X)$
Drell Yan A_{TT}
Heavy Flavor A_N

W Production

$A_L(u + \bar{d} \rightarrow W^+ \rightarrow \ell^+ + \nu_\ell)$
 $A_L(\bar{u} + d \rightarrow W^- \rightarrow \ell^- + \bar{\nu}_\ell)$

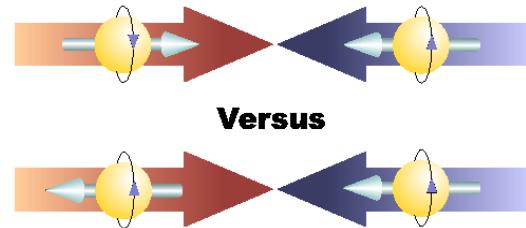


Outline

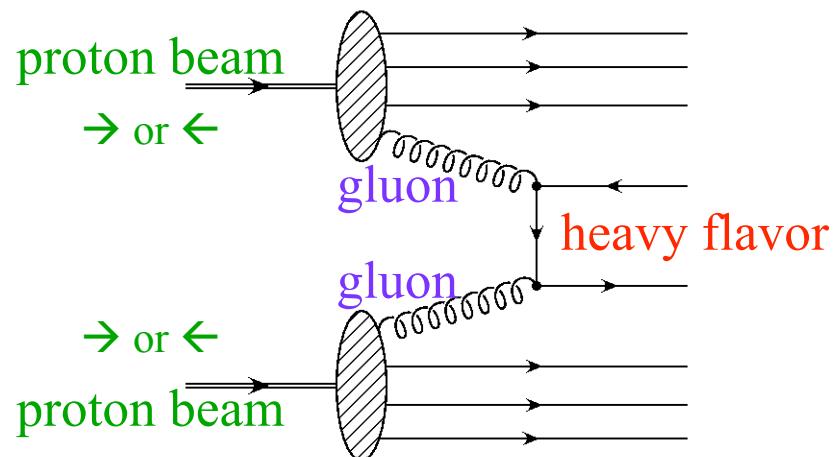
- $J/\Psi A_{LL}$
 - for delta G
- $J/\Psi A_N$
 - for gluon's Sivers function
- **outlook**
single muon/electrons and VTX and FVTX
upgrade

Gluon Polarization (RHIC)

- Polarized hadron collision
 - double longitudinal spin asymmetry



- leading-order gluon measurement
 - direct-photon production
 - heavy-flavor production



Heavy Quark Production @PHENIX

- Sensitive to gluon polarization: $\Delta g(x)$
- Gluon Fusion dominates at LO

PYTHIA estimate:

GeV	Charm	Beauty
200	95:5	85:15
500	97:3	92:8

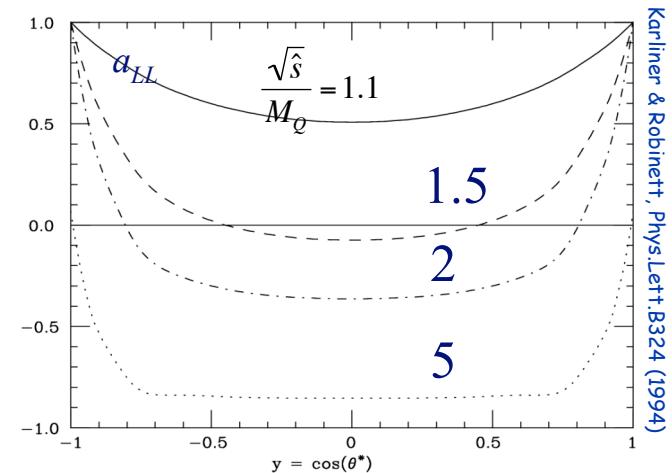
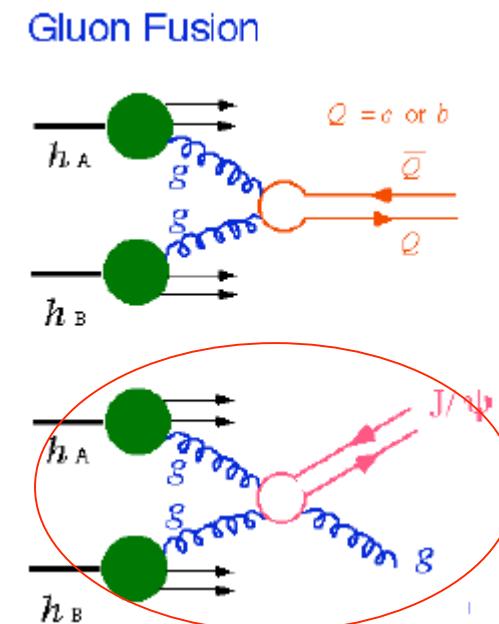
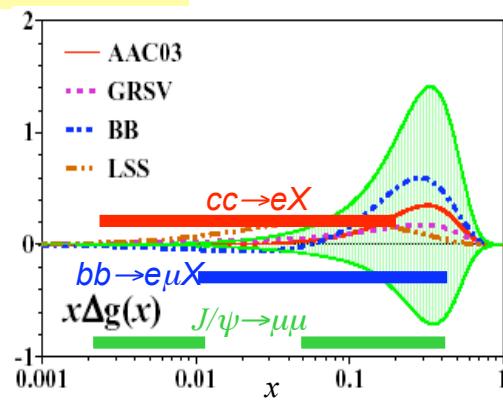
$$\sigma(gg \rightarrow Q\bar{Q}) : \sigma(q\bar{q} \rightarrow Q\bar{Q})$$

Double spin asymmetry:

$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \frac{\Delta g(x_2)}{g(x_2)} a_{LL}^{gg \rightarrow Q\bar{Q}}$$

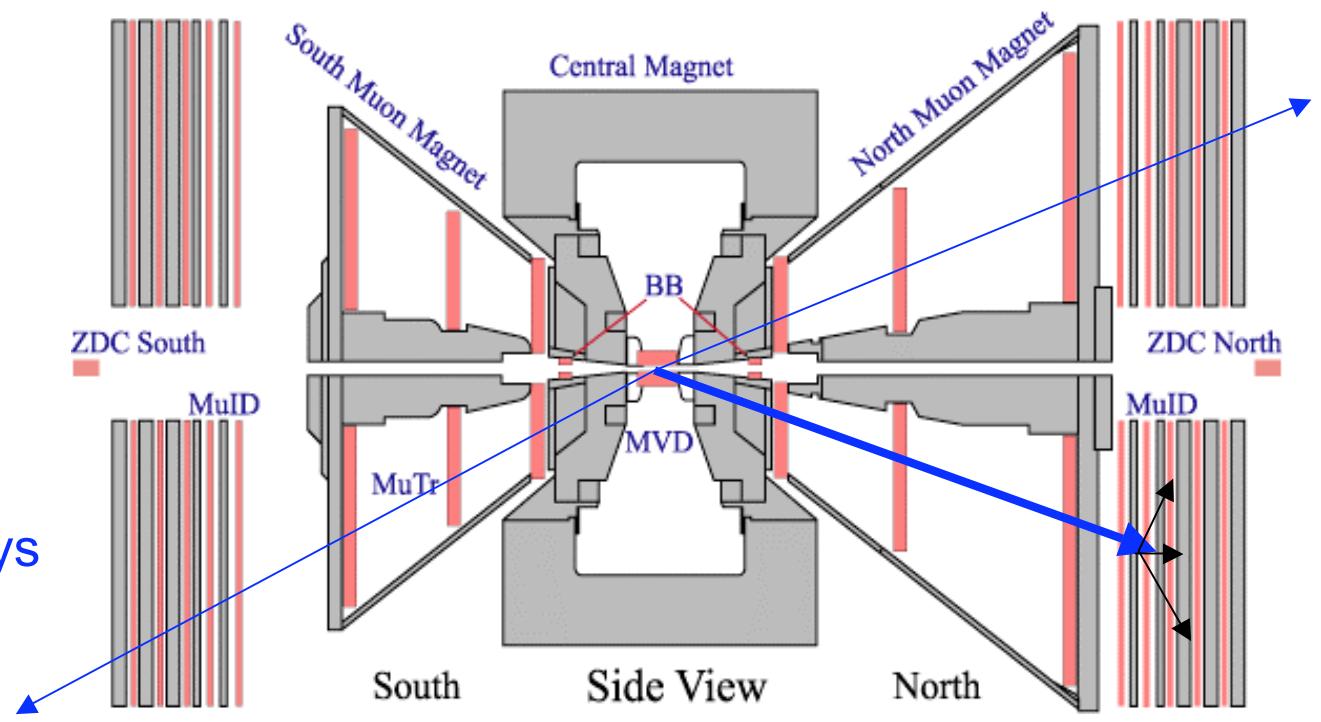
Decay modes:

$$e^+e^-, \mu^+\mu^-, e\mu, eX, \mu X$$



PHENIX Muon Detectors

- Muon arms
 - $1.2 < |\eta| < 2.4$
 - $\Delta\phi = 2\pi$
 - $P > 2\text{GeV}/c$
 - Triggers
- “Muons”
 - Stopped hadrons
 - Light meson decays
 - Heavy decays
 - J/Ψ
 - Open charm



J/Ψ from Y06 Data

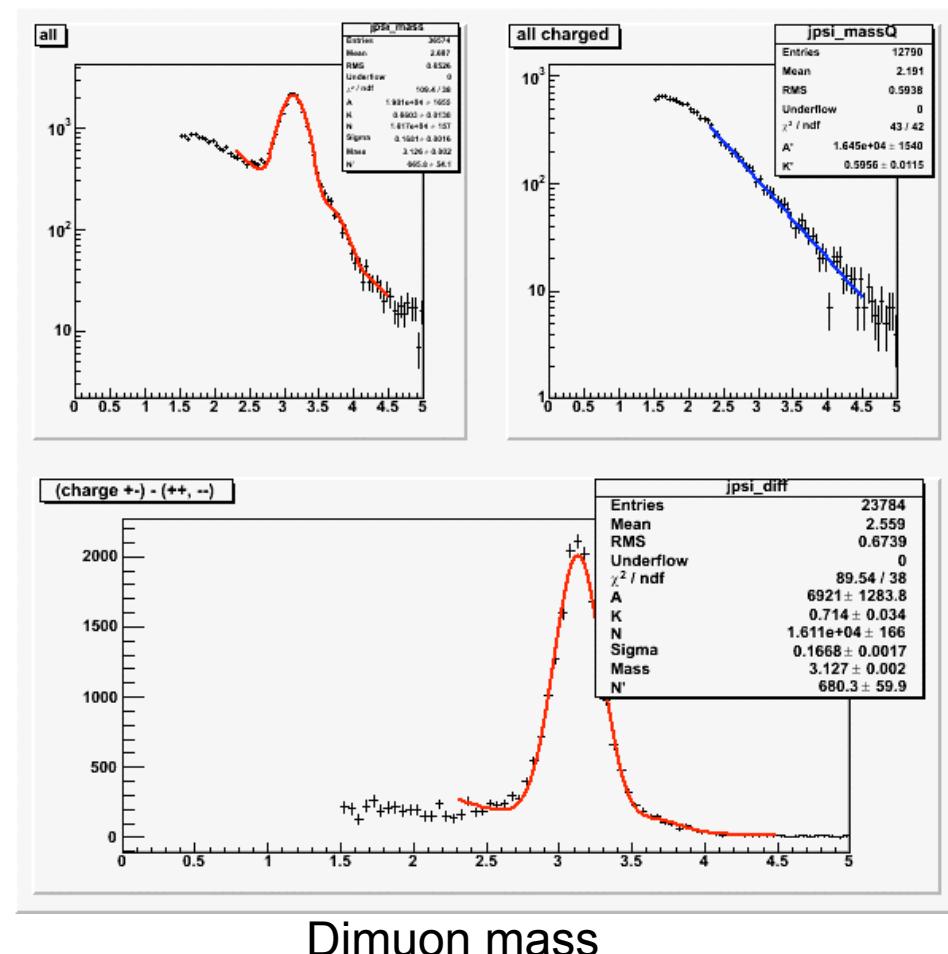
- Run6 pp dimuon events:

Longitudinal Polarized

- 5 Pb⁻¹ from LVL-2
- 16K

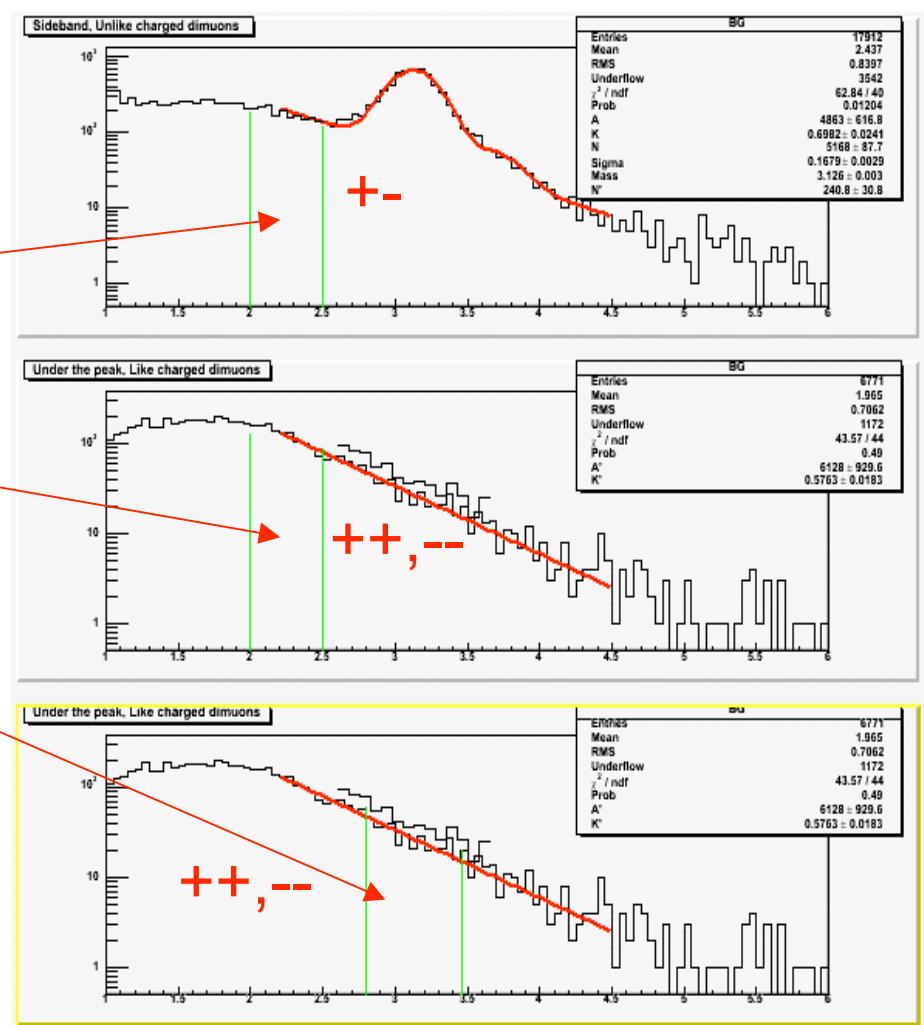
Transverse Polarized

- 1.7 Pb⁻¹ from LVL-2
- 6K



Background estimation

- From Drell-Yan, Open charm, Light hadrons, etc.
- Three methods:
 - Sideband from unlike sign dimuon pairs:
 $1.8 < m < 2.5$
 - Sideband from like sign dimuon pairs:
 $1.8 < m < 2.5$
 - Same sign dimuon pairs under the J/ Ψ peak



A_{LL} calculation

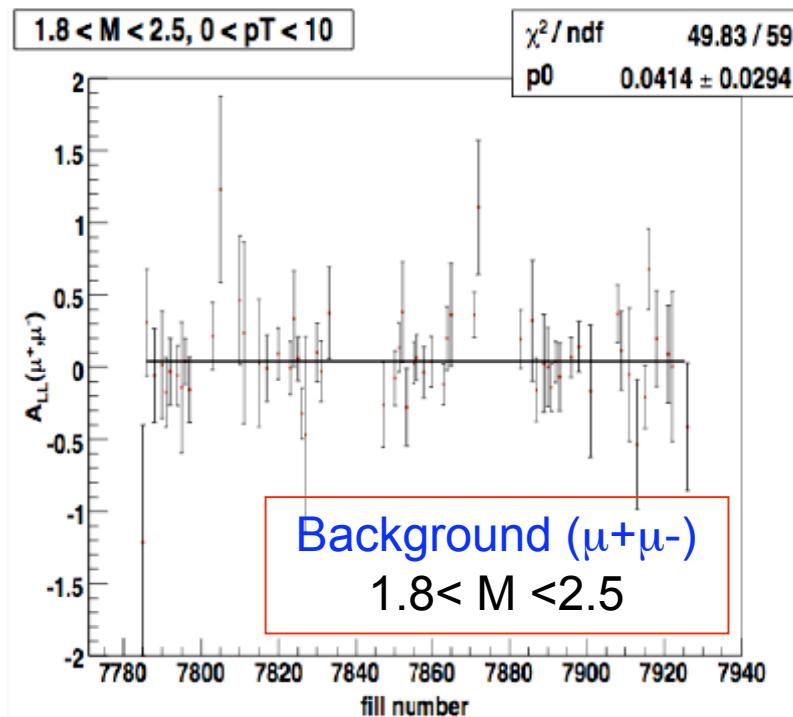
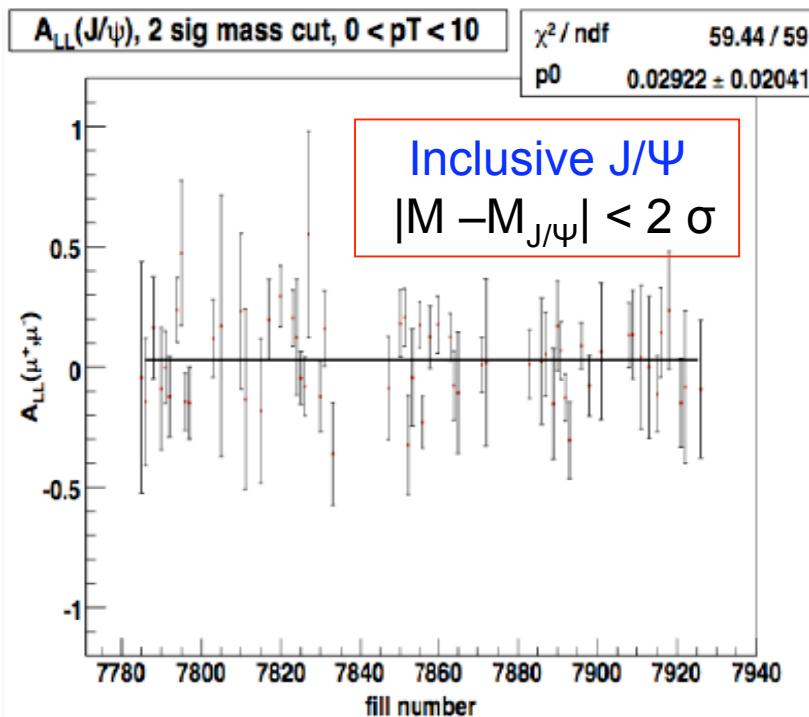
$$A_{LL}^{incl(BG)} = \frac{1}{\langle P_B \rangle \langle P_Y \rangle} \frac{N^{++} - R \cdot N^{+-}}{N^{++} + R \cdot N^{+-}}$$

$$A_{LL}^{J/\Psi} = \frac{A_{LL}^{incl} - f_{BG} \cdot A_{LL}^{BG}}{1 - f_{BG}}$$

$$\delta A_{LL}^{J/\Psi} = \frac{\sqrt{(\delta A_{LL}^{incl})^2 + f_{BG}^2 \cdot (\delta A_{LL}^{BG})^2}}{1 - f_{BG}}$$

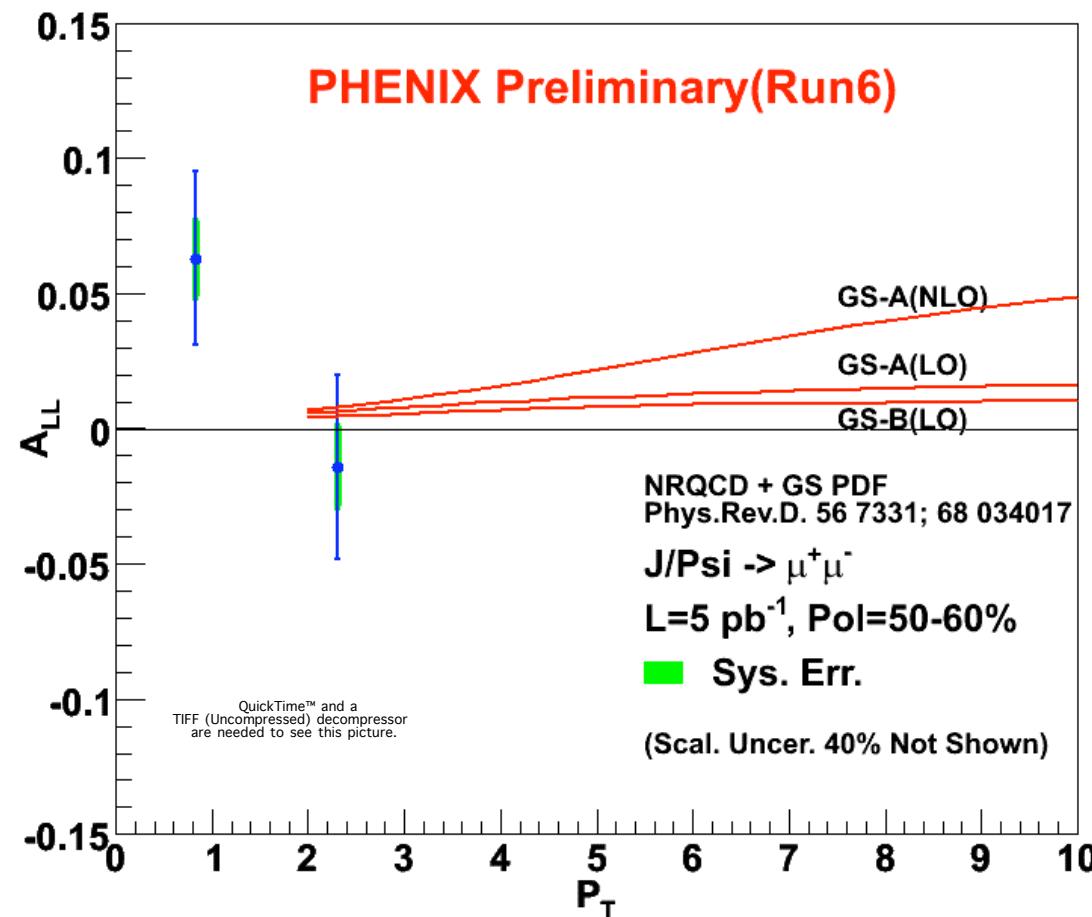
Experiment approach:

- Fill-by-Fill analysis
- Inclusive J/Psi events
- Background estimation S/B~10
- P → from CNI
- R → BBC and ZDC



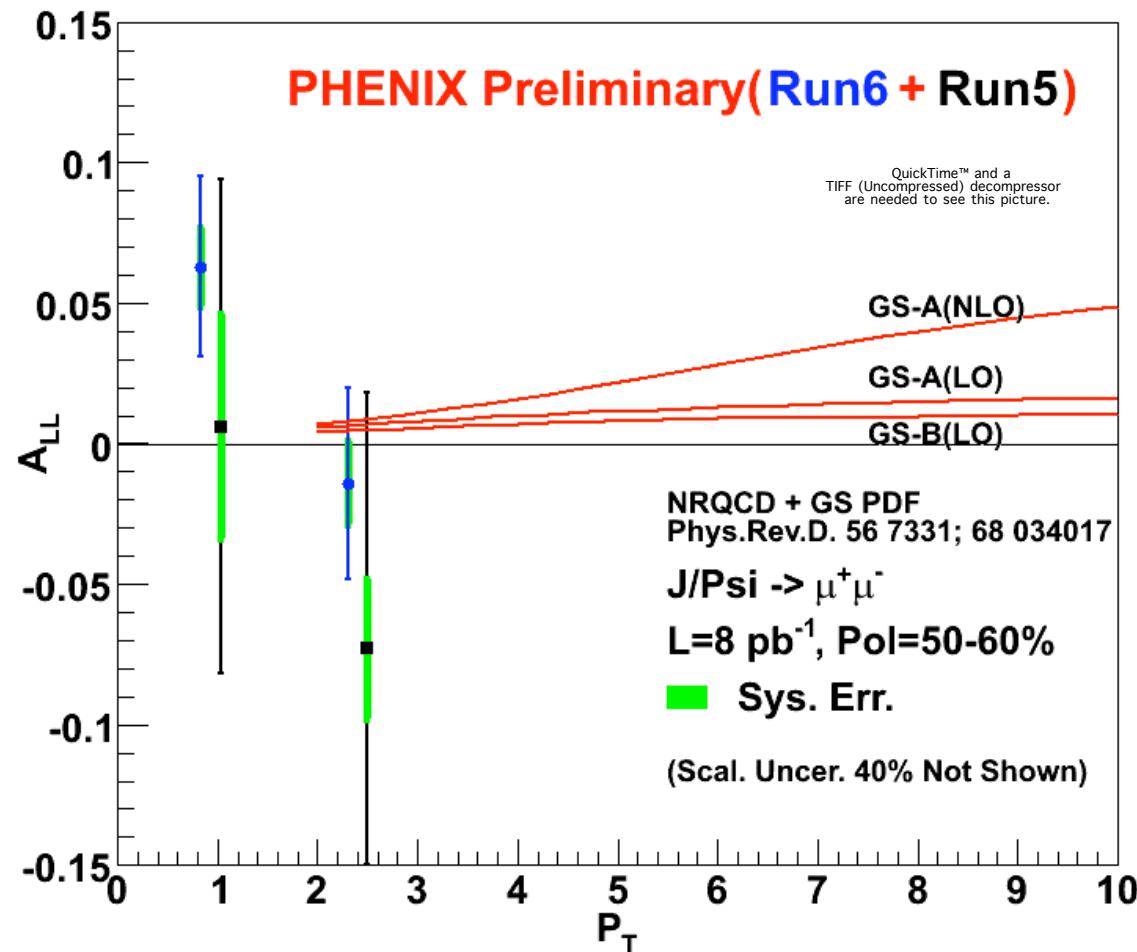
J/ Ψ A_{LL} from Run6

J/Psi: $|y| = 1.2-2.4$



J/ Ψ A_{LL} from Run5+6

J/Psi: $|y| = 1.2-2.4$



A brief history for transverse single spin asymmetries

-- Naïve parton model

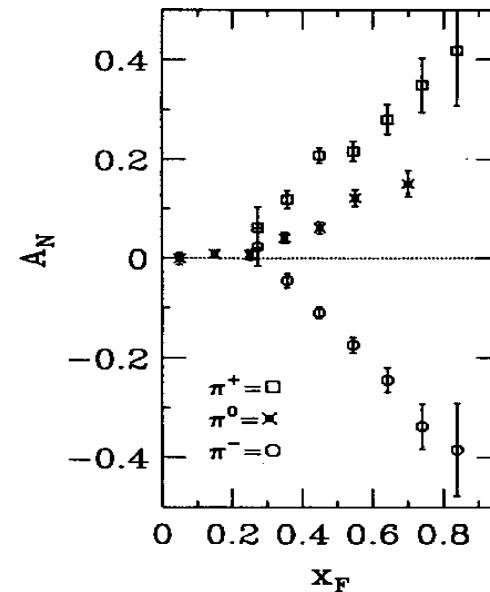
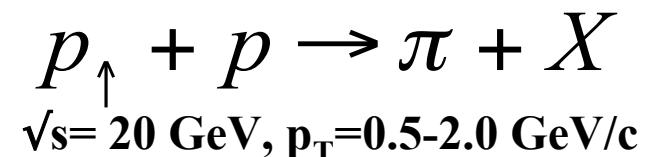
pQCD predicts small analyzing powers
in transversely polarized p+p collisions

$$A_N \propto \frac{m_q}{\sqrt{s}} \quad (\text{for example, } m_q = 3 \text{ MeV}, \sqrt{s} = 20 \text{ GeV}, A_N \approx 10^{-4})$$

-- FermiLab E704 experiment

Found strikingly large transverse
single-spin effects in $p\uparrow + p$ fixed-
target collisions with 200 GeV
polarized proton beam

-- Large AN persist at RHIC energy



π^0 : PLB261 (1991) 201

$\pi^{+/-}$: PLB264 (1991) 462

Theoretical efforts

Four different mechanisms have been proposed to explain this asymmetries

- **Sivers effect**
 - Transverse momentum dependent quark and gluon distributions give rise to correlation between transverse proton spin and the transverse momentum k_T of quarks and gluons
- **Collins effect**
 - Transversity distributions + spin dependent fragmentation functions
- **Higher-twist effects**
 - Quark gluon field interference
 - * Sterman and Qiu → Initial State Twist 3
 - * Koike → Final State Twist 3

A coherent treatment of the Sivers effect and quark gluon correlations at higher twist has been provided by Ji, Qiu, Vogelsang and Yuan ([PRL97:082002,2006](#))

- Or some combination of above

Single Spin Asymmetry calculation

Definition:

$$A_N \equiv \frac{\sigma^{\uparrow}(p) - \sigma^{\downarrow}(p)}{\sigma^{\uparrow}(p) + \sigma^{\downarrow}(p)} = \frac{\Delta\sigma(p)}{\sigma(p)}$$

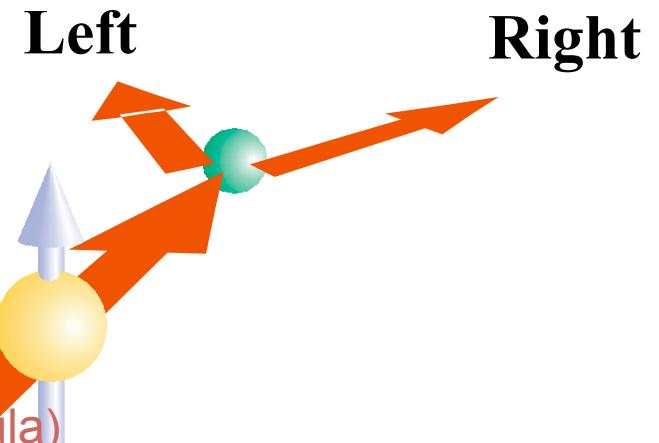
where p is the 4-momentum of a particle (hadron, jet, photon, etc...)

Experimentally, there are a variety of (~equivalent) ways this can be measured.

1. Yield difference between up/down proton in a single detector

$$A_N = \frac{1}{P_{\text{beam}}} \frac{N^{\uparrow} - R_{\text{lumi}} N^{\downarrow}}{N^{\uparrow} + R_{\text{lumi}} N^{\downarrow}} \quad R_{\text{lumi}} = L^+ / L^-$$

This is susceptible to Rel. Luminosity differences



2. Or, take the cross geometric mean (square-root formula)

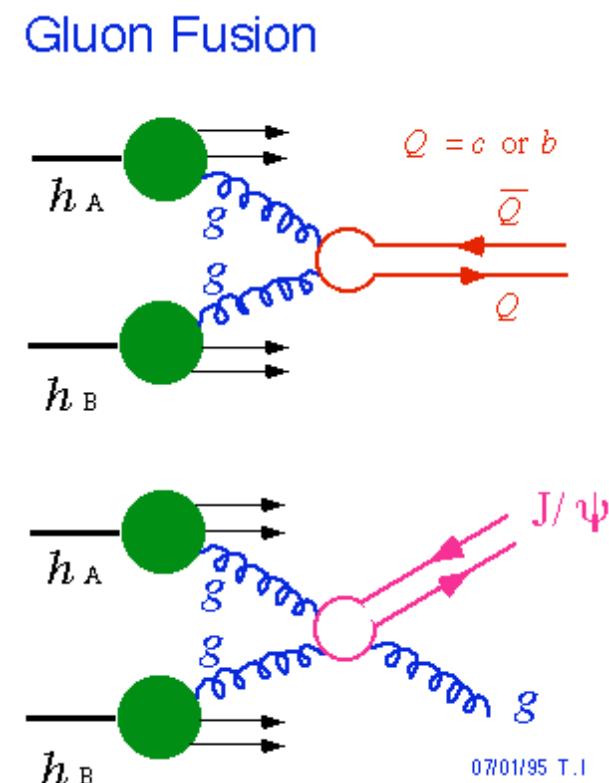
$$A_N = \frac{1}{P_{\text{beam}}} \frac{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} \cdot N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} \cdot N_R^{\uparrow}}}$$

Mostly insensitive to Relative Luminosity and Detector Acceptance differences

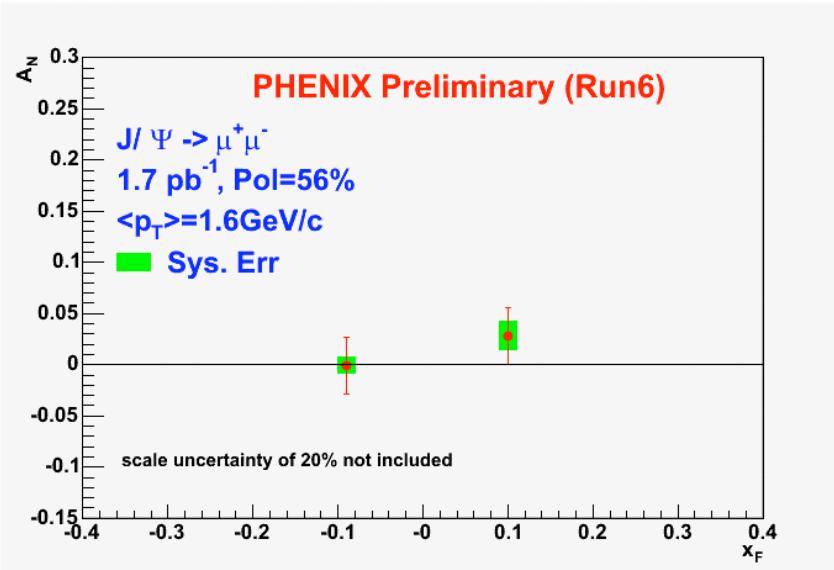
J/ψ A_N

Why J/ψ?

- Eliminate Collins' effects
 - * J/ψ production dominated by gluon gluon fusion at RHIC energy
 - * gluon has zero transversity
- A perfect channel for gluon Sivers function
- Important to understand the origin of observed large A_N at large x_F



A_N VS. X_F

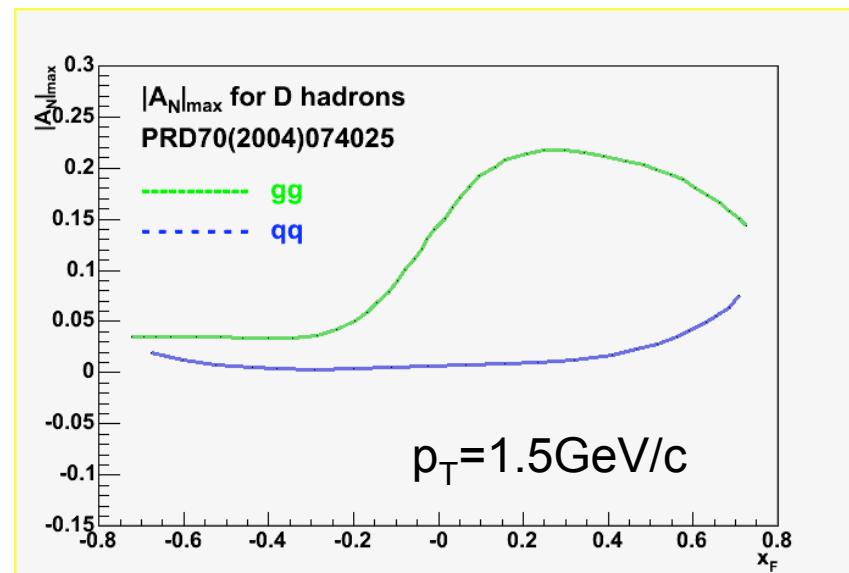


*How does J/ψ production affect prediction?
Waiting for theoretical calculation

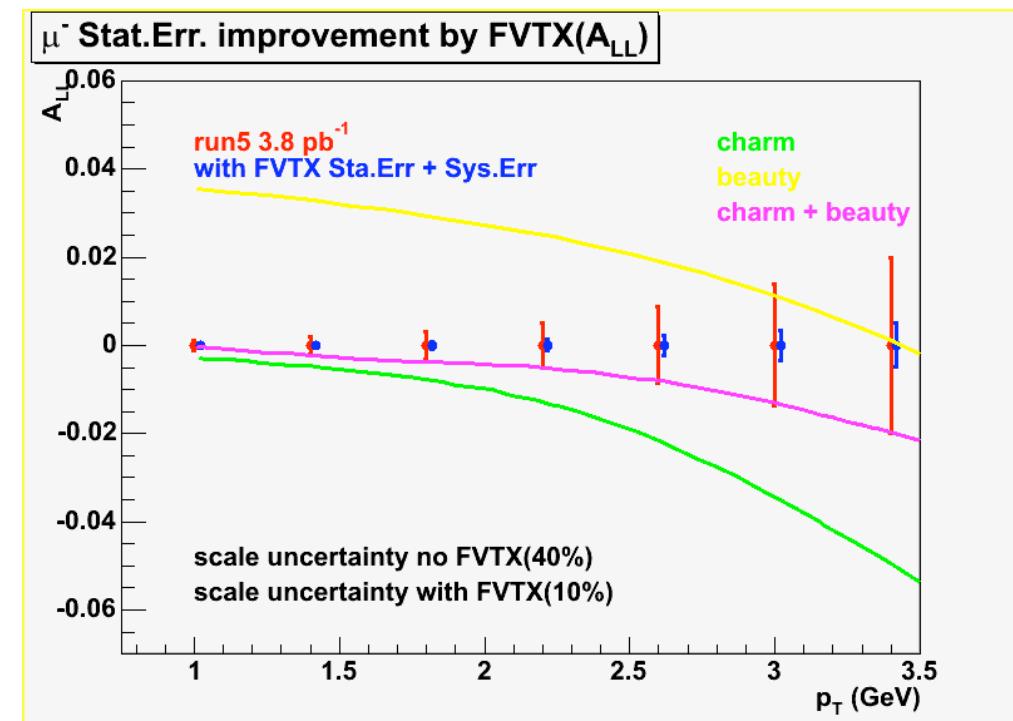
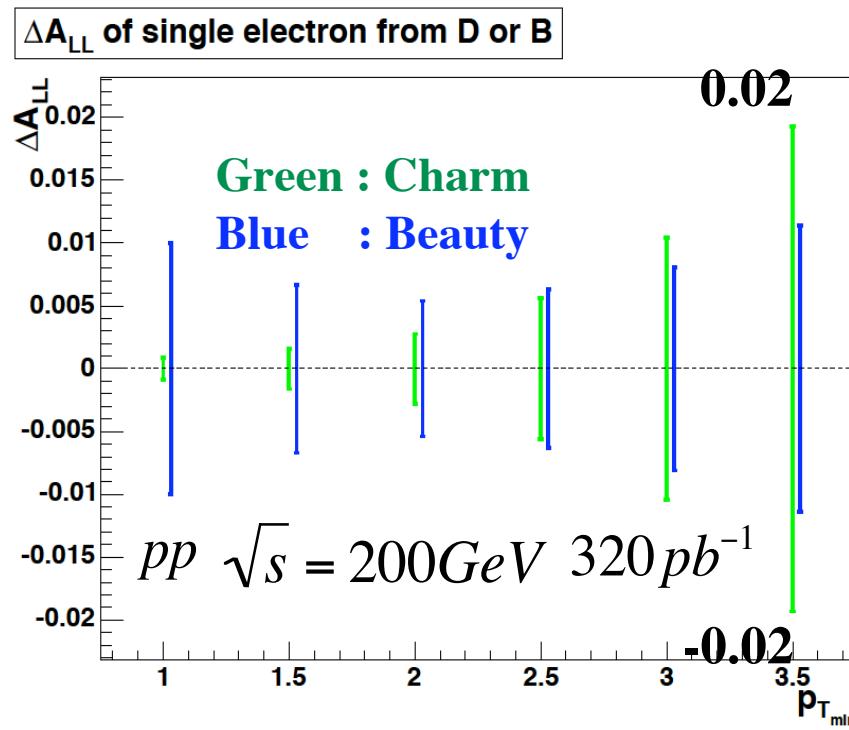
* If A_N comes from the initial state → Disfavor the maximum contribution of gluon Sivers function

Theoretical prediction:

Only available for open charm production
--quark Sivers function set to its maximum
gluon silver function set to 0
--gluon Sivers function set to its maximum
quark silver function set to 0



Heavy Flavor with VTX and FVTX



Summary and Outlook

- Gluon polarization with J/ Ψ from Y05 and Y06 p-p collisions
- transverse single spin asymmetry with J/ Ψ at $x_F \approx \pm 0.1$ from Y06 p-p collisions
- A_N measurement disfavor the maximum contribution of gluon Sivers function
- The theoretical work in progress
- Promising heavy flavor spin measurement with VTX and FVTX upgrade.